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HELICOPTER IN-FLIGHT SIMULATION DEVELOPMENT AND USE IN TEST PILOT TRAINING

R. V. Miller* and L. A. Khinoo**
U. S. Naval Test Pilot School
Naval Air Warfare Center Aircraft Division
Patuxent River, Maryland

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The U. S. Naval Test Pilot School (USNTPS) trains pilots, flight officers and engineers in the technical and managerial skills necessary to conduct aircraft and airborne systems test and evaluation. An integral part of this training is the use of ground and in-flight simulators to demonstrate the effects of varying aircraft flying qualities parameters. The USNTPS has developed specialized simulation facilities to meet the unique training requirements. This paper describes the development of a Variable Stability and Control (VSC) system installed in an SH-60B helicopter as a specialized training aid for use at the USNTPS. The development of the VSC system is traced from requirements through syllabus introduction.

Introduction

The U. S. Naval Test Pilot School, at NAS Patuxent River, Maryland, is a Directorate of the Flight Test and Engineering Group (FTEG), Naval Air Warfare Center Aircraft Division. (The FTEG was formerly the Naval Air Test Center.) The FTEG is responsible for conducting test and evaluation of aircraft, systems, components, and related equipment. In support of this mission the USNTPS trains test pilots, test flight officers, and test project engineers to conduct these evaluations. Graduates are involved in important decision-making processes regarding future aircraft and airborne systems acquisitions and upgrades.

Overview of Curricula

Instructional Approach

The instruction at the USNTPS is comprised of classroom lectures, briefings, simulation and flight test exercises. The test pilot applicant is a highly motivated and experienced aviator with a B.S. degree and many times an M.S. degree in engineering, mathematics or the physical sciences. The relatively short time span of 11-months necessitates a unique instructional approach. The instruction is aimed at improving analytical flying skills, developing analytical writing ability, and expanding aircraft and mission knowledge through increased exposure to a wide variety of aircraft and systems types. These principles are basic to the course of instruction and have guided the design of the integrated academic, flight and report curricula at the school.

Curricula

The course of instruction offers three separate curricula: fixed wing, rotary wing, and airborne systems. Although common in many respects, each curriculum contains specialized academic courses and flight test exercises.

Academic Instruction

Two to four hours a day are devoted to formal academic instruction with a total of approximately 480 classroom hours. The academic courses are tailored to provide the student with the required technical background to support the flight projects. The academic courses are categorized as engineering, aircraft performance, aircraft flying qualities, airborne systems, and other specialized subjects.

The use of the VSC system is most revelant to the flying qualities courses which address both fixed wing and rotary wing stability and control. In these courses, the basic governing equations of motion are derived and

* Academic Instructor
** Flight Instructor, Veda Inc.

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then used to interpret the various flight test methods. The synergistic effects of control system, cockpit displays, and visual cueing are discussed and demonstrated.

Flight Instruction and Reports

Each student completes 40 to 50 flight projects that include test planning, project flying, and reporting of test results. In each exercise, the technical background developed in the classroom is applied to flight exercises where the student is charged with documenting the characteristics of the aircraft or system in an engineering sense and with evaluating it qualitatively to determine the potential of satisfying operational requirements. On each exercise, engineering data are obtained and processed into an acceptable form for inclusion in the technical report. These data, along with qualitative evaluations pertaining to items of mission relation, are the basis for the final report.

Aircraft

The flight program is supported by a stable of 38 USNTPS aircraft,currently including F-18, T-2, T-38, U-21, U-1, U-6, UH-60, SH-60, H-58, OH-6 and the X-26 glider. During the course, all pilots will fly 12-14 different types of aircraft. In addition, variable stability and control (VSC) aircraft are employed to demonstrate to each student the wide variety of parameters that affect handling qualities. Currently employed VSC aircraft are the Calspan Corporation Learjet Model 24, USAF NT-33 aircraft, and the USNTPS NSH-60B helicopter. The T-33 is soon to be replaced by the Variable stability In-flight Simulator Test Aircraft (VISTA) F-16.

The Use of Simulation at USNTPS

General

The USNTPS has developed specialized ground and airborne simulation facilities to meet the school's unique training requirements. In-flight and ground based simulators are used to teach flying qualities and control system characteristics. A primary objective of the flying qualities instruction is to demonstrate the effects of each of the elements of the pilot-vehicle system illustrated in figure 1. The simulator typically uses a control system loader to vary the desired feel system characteristics such as breakout, friction, and spring gradient. A variable display system is used to present a range of display formats and show the effects of display dynamics.

Use of Ground-Based Simulation

Ground-based simulation has been employed as a training aid at the USNTPS since 1969 [1]. The role of USNTPS ground-based simulation is similar to the in-flight simulation. The advantages of ground based simulation include: more controlled conditions, increased availability, use for demonstration and practice of conditions that would be unsafe for in-flight simulation, lower cost to procure and operate, and an effective way to prototype in-flight VSC exercises.

Unfortunately the results from handling qualities tests conducted in ground simulators are often misleading due to distortions caused by the limited visual and motion systems. One objective of using both ground and inflight simulation is to demonstrate the limits of evaluations conducted in ground simulators. The increased use of ground based simulation in RDT&E requires that the test team understand these limitations and the utility of ground base simulations. The exposure of the USNTPS student to a range of ground and inflight simulators provides the background necessary to fully utilize simulators as a T&E tool.

The use of ground-based simulation represents an important step in the systematic progression from the concepts presented in the classroom to the real world environment where the flight tests are performed. The high fidelity Manned Flight Simulator at the NAVAIRWARCENACDIV and the low cost USNTPS simulators provide the facilities necessary for effective training of the test pilot and flight test engineer.

Because of these relative advantages and limitations, the ground-based simulation role is viewed as being complimentary to in-flight simulation

and is being actively pursued along with the in-flight simulation.

In-Flight Simulation Vi VSC System

In-flight simulatio: .s been used as a teaching tool at USNTPS since the introduction of the B-26 VSC aircraft in 1960. The unique role of the VSC aircraft programs has been to provide flying laboratories in which the student evaluator can relate the engineering parameters of aircraft stability and control to their effect on the flying qualities of the aircraft. With the VSC aircraft, the evaluator can be exposed to a wide range of flying qualities in reali: mission related airborne tasks.

In-flight simulators are implemented via a VSC system which is a modification of the flight control system that allows in-flight variation of the flying qualities of the host aircraft. The major elements of the pilot closed loop system are the pilot, display system, feel system, aircraft, sensors, VSC computers, and servo actuators (figure 1).

VSC Operating Modes

VSC operating modes are typically categorized as "response feedback" or "model following". These modes are described below.

Response Feedback VSC - In this mode the VSC system parameters controlled are the feedback, feedfoward, and shaping parameters. The VSC parameters are closely related to aircraft stability derivatives. The aircraft modal characteristics would typically vary with flight conditions.

Model Following - In this mode the VSC system parameters are model parameters such as frequency or damping ratio. The pilot's control input drives a VSC math model and the VSC system then attempts to drive the VSC aircraft to follow the math model response. In this mode the aircraft response characteristics tend to be invariant with aircraft configuration and flight conditions.

The response feedback mode is used in all of the current USNTPS applications.

Use of VSC in Curriculum

A chronology of the significant VSC system milestones at USNTPS is

1960 - First VSC syllabus flights in B-26
1972 - VSC NCH-46 introduced
1974 - VSC NT-33A introduced
1981 - VSC Learjet model 24 introduced
1981 - VSC X-22A V/STOL introduced
1982 - VSC NCH-46 modernization program completed
1987 - Helo VSC replacement program initiated

The variable stability flight program consists of a series of coordinated classroom lectures, ground-based simulations, preflight briefs and flight demonstrations. The flights are spaced throughout the school year and address topics such as basic aircraft dynamics, test techniques, advanced flight control systems, and handling quality evaluations. The flights build on the concepts introduced in the academic courses and enhance the ability of the prospective test pilot to make handling quality evaluations. In addition, flight experience is expanded by showing the evaluation pilot a variety of unusual and undesirable aircraft characteristics. These flights have proven to be extremely valuable as a tool to teach the fundamentals of analysis and correction of flight control system deficiencies.

During the 11-month program, each pilot participates in five VSC training flights. The engineer and flight officer receive up to three VSC flights. All of the VSC flight and associated lectures, except the VSC NSH-60B, are conducted by Calspan. The annual syllabus use of VSC aircraft at the USNTPS is approximately 200 flights for the VSC Learjet and 45 flights for the NT-33A. The projected annual utilization of the NSH-60B in the VSC training role is approximately 50 flights. A summary of the VSC flights for the Rotary Wing curriculum are summarized below.

Rotary Wing VSC Flights

Flight	Aircraft	Subject
1	Learjet	Long Stab Demo
2	Learjet	Lat-Dir Demo
3	Learjet	S&C Review
4	NT-33A	Advanced Flight Controls Demo
5	NSH-60B	Lat FQ Demo
6	NSH-60B	Response Types & Coupling

NSH-60B VSC Program Overview

Background

A program was initiated in 1987 to replace the CH-46 VSC aircraft [2]. A chronology of significant program milestone is

1987 - NCH-46 replacement program initiated
1988 - VSC NCH-46 returned to the fleet
05/91 - VSC requirements established - Statement of Work (SOW)
12/91 - VSC SH-60 contract awarded
06/91 - SH-60B delivered to contractor
10/91 - Ground test
10/91 - Phase I flight test
11/91 - A/C ferried to USNTPS
01/92 - Phase II flight test starts
09/93 - Interim VSC flight exercise
06/94 - VSC I for USNTPS Class 106
08/94 - VSC II for USNTPS Class 106

Engineering and syllabus development tests for a third VSC exercise are scheduled for 1994.

Airframe Selection

The selection of the H-60 series helicopter as the host VSC aircraft was based on aircraft availability, supportability at the USNTPS, and the demonstrated SAS authority and bandwidth. A review of existing flight test data, analysis, and manned simulation test, indicated that the approximate ± 10% SAS authority would provide adequate angular acceleration for a VSC system in the roll and pitch axes, and marginal angular acceleration in the yaw axis. In June of 1992 an SH-60B aircraft BuNo 162974 was transferred to the USNTPS for the VSC system installation.

Test Aircraft Description

The NSH-60B is a single piloted, single main rotor, twin-engine helicopter manufactured by Sikorsky Aircraft. The main rotor system consists of a fully articulated, four-bladed rotor with a hinge offset of 4.7%. The tail rotor, mounted on the starboard side, is a four-bladed, tractor type, canted 20 degrees from the vertical. The side-by-side cockpit has dual conventional flight controls. The hydraulically boosted and irreversible flight controls incorporate mechanical mixing to minimize inherent control coupling. An AFCS is incorporated to assist the pilot in maneuvering and controlling the aircraft. The AFCS is composed of three major subsystems: the Stability Augmentation System (SAS), Stabilator System, and Digital Automatic Flight Control System (DAFCS). The aircraft maximum gross weight is 21,700 pounds. The sonobuoy launcher, spectrum analyzer, and other mission avionics equipment have been removed. A flight test instrumentation system and the VSC system have been installed. The aircraft can be reconfigured by removing the VSC kit so that mission avionics such as the Radar or Doppler TACNAV, and multipurpose display can be re-installed.

Instrumentation

The VSC Helicopter is equipped with a MARS 2000 wide band airborne recorder, a PCM encoder and associated pre-conditioning filters. Up to 48 channels of analog data at 85 samples per second may be recorded with 12 bit resolution.

Helicopter VSC Requirements

The USNTPS VSC basic program requirements were to replace the function of the NCH-46 VSC and, where feasible, upgrade the school's helicopter in-flight simulation capability. An assumption was that the rotary wing student would continue to use the Learjet, T-33, and ground base simulator and that the VSC would be primarily used in the hover.

The VSC system will allow the demonstration of the effects of varying stability and control parameters about the pitch, roll and yaw axes. The response feedback method was specified

based on its successful use in the CH-46 and other USNTPS VSC applications. Other significant SOW requirements included:

- Maximum use of host aircraft sensors and actuators
- Notch filters for specified sensor signals
- First order lead/lag in signal flow paths
- A safety trip system (method not specified)
- Ability to change VSC configuration within 30 sec.
- VSC data bus
- Servo command bus
- Selected inter-axis coupling
- VSC in kit form
- Test plan for ground and flight test
- Frequency response test for SAS actuators

VSC Implementation

The design fabrication and installation of a VSC in an SH-60B was contracted in 1991. The host aircraft was delivered to Calspan in June of that year. The Calspan approach [3] for this design was to use an adaptation of the proven Learjet VSC system.

The VSC hardware installed includes:

- VSC Control Panels
- VSC Electronics Enclosures
- SAS/VSC Relay Transfer Enclosure
- 3-Axis Rate Gyro Package
- Position Transducers

There are no special provisions for varying the cockpit control feel characteristics.

The NSH-60B VSC uses the existing ship's SAS actuators and attitude gyros sensors. Additional VSC sensors are control position transducers and VSC rate gyros. The various feedback signals are then shaped (first order lead-lag), amplified, and summed according to the programmed response and sent to the limited authority SAS series actuators. Sensor signals from one channel can be cross coupled to the other channels.

VSC Operation

When the VSC is engaged, inputs to the limited authority SAS actuators are transferred from the host aircraft flight control computers to the VSC computer via the SAS/VSC Relay Transfer.

Typically the safety/instructor pilot occupies the left seat and the evaluator/student occupies the right seat. The VSC can be flown from either seat when the VSC is engaged.

The VSC can be manually disengaged by either pilot if an unsafe condition is encountered. The VSC also has automatic safety trips that disengage the system. The trips are actuated when the difference between the commanded and actual actuator position is greater than a specified threshold (in volts), for a specified time. The specified values for the development program were 4 volts (10 volts is full actuator throw) and 100 ms. When disengaged, control of the SAS actuators revert back to the host aircraft flight control system. The reversion is to either a SAS ON or SAS OFF aircraft depending on which mode was selected at engagement.

The response-feedback flight control system is programmed through digital computer controls located in the cockpit.

Configuration Control System

The configuration control system (CCS) replaces the manually adjusted potentiometers used in the VSC NCH-46. The CCS allows up to 256 VSC configurations (sets of 64 VSC system gains) to be quickly set during flight or ground operation. Of these 256 configurations, 128 are permanent and the remaining 128 temporary configurations can be defined and stored during normal flight or ground operation.

VSC Flight Test Program

Objectives and Scope

Initial program objectives were to safely develop the maximum VSC gain envelope and then develop two syllabus exercises within this envelope. The two exercises would be similar in purpose to the NCH-46 VSC I and VSC II exercises previously used in the curriculum.

Tests were conducted during two phases. Phase I tests, acceptance and functional evaluation, were conducted at the Calspan flight test facility in Buffalo, N. Y. The Phase II tests, engineering and syllabus development, were conducted at NAWCAD, Patuxent River.

Phase I test consisted of ground tests and 3 test flights totaling 6 hours. Phase II of tests were conducted at Patuxent River consisted of 27 test flights totaling 50.6 flight hours.

Phase I Tests

The objective of the Phase I flights was to verify the basic functioning of the system and to make sure that the systems was performing correctly before returning to USNTPS. Specific tests objectives were to:

- Verify airborne function of the system and fulfill contractual requirements for VSC System Acceptance
- Evaluate the aircraft fault monitoring systems with VSC engaged
- Verify safety trip system operation and adjust thresholds
- Assess input signal quality and implement filters
- Generate baseline open loop data
- Initiate the gain increases
- Monitor system performance to identify any tendencies toward high frequency instabilities

Phase II Tests

Follow on Phase II engineering development tests at Paxtuxent River were aimed at continuing Phase I objectives and incrementally increasing each gain to establish the gain envelope. Final refinements to the system such as signal conditioning and the trip system adjustments were made. After the VSC configuration was frozen, the last task was the development of two VSC exercises.

Test Envelope

All tests were conducted within the NATOPS flight envelope for the SH-60B, as modified by the NAVAIR flight clearance. Hover tests were ground referenced and initially conducted at 300 feet AGL, which is above the single engine H-V diagram for the test aircraft. As confidence in the VSC system was gained, the tests were conducted at lower altitudes where the visual cueing was adequate for precision hover tasks. A minimum altitude limit of 20 feet AGL was observed for all tests.

Test Methods

General flying qualities test methods and procedures were in accordance with USNTPS "Rotary Wing Stability and Control" Flight Test Manual [4]. A specialized test method was the frequency sweep which was used to generate the frequency response data. This data was used to determine the gain and phase margin of the system which was the primary method for tracking the stability of the VSC system/aircraft combination.

Threat Analysis

Preflight analysis was performed to determine potential "threat" modes of failure and general hazards. The contractor conducted a System Safety Hazard Analysis [5] and several threats were identified. The threats or hazards are classified into two groups: Group 1 - threats or occurrences leading to a SAS actuator hardover; and Group 2 - threats or occurrences leading to an oscillatory behavior of the SAS actuator.

Failures Leading to Hardover

This failure mode could be the result of a VSC system failure or an aperiodic divergent aircraft mode. The effects of this failure mode were considered to be acceptable based on review of Sikorsky's SAS hardover flight tests, and USNTPS staff evaluations of SAS hardovers in a NASA UH-60 simulation. The VSC induced hardovers are no more critical than production SAS hardovers, and are equivalent to flying the aircraft with the SAS off, with a one inch bias in the longitudinal or lateral cockpit control positions. This failure mode is considered safe as long as the aircraft is operated with at least two inches of cyclic control margin.

Failures Leading to Oscillatory SAS Actuator

Several oscillatory modes were considered to be threats because of the possibility of relatively small

(± 10%) oscillatory SAS actuator motion exciting large amplitude rotor or structural motions. The degree of threat was considered to be related to the frequency of the mode as compared to the bandwidth of the VSC system. If the frequency of the mode being considered was significantly higher than the bandwidth of the system, the potential threat of the VSC to interact with the mode to cause a instability was low. If however the frequency of the mode under consideration was equal to or less than the bandwidth of the VSC system (including actuators), then the possibility of an adverse interaction between the VSC and the mode was treated as a real threat.

VSC System Bandwidth

In order for the VSC system to contribute to an oscillatory failure mode a signal from the VSC sensor would have to pass through the sensor, VSC computer, and SAS actuator. The bandwidth of this system is primarily limited by the bandwidth of the VSC computer and the SAS actuator.

The VSC computer bandwidth is determined by an analog lowpass second order filter with a bandwidth of 5 Hz. The filtering provided by the SAS actuator was determined by bench tests and verified during in-flight tests. These tests show that the SAS actuators can be modeled as fourth order with a bandwidth of approximately 5 Hz.

The combined VSC computer and SAS actuator form an effective sixth order low pass filter with a bandwidth (conservative) of 5 Hz. This frequency served as a rough discriminator of which excitation or modal frequency would be considered a threat.

Threat Modes

Surveys of SH-60 airframe structural data, general rotor dynamics literature, and interviews with subject matter experts highlighted several modes which represented potential threats. These modes are:

Lead-Lag Regressive - The rotor lead-lag regressive mode was identified [6] as a lightly damped mode that can couple with rigid body mode to produce an instability when an angular rate signal is fed back to the same axis rotor control (e.g. roll rate feedback to lateral cyclic). At the time of the test there were no data available to identify this effect for the SH-60B however an estimated value of the lead-lag regressive mode frequency was 3.2 Hz for the UH-60. This frequency was used as an initial estimate for the NSH-60B, and served to localize the search for instabilities during subsequent data analysis.

Tail Shake - A significant threat was identified as the tail shake mode. A survey of airframe structural data indicated a first lateral bending mode of the fuselage occurred at approximately 5 Hz and a first vertical bending mode at 6 Hz. Supporting this concern were NATOPS and fleet reports of a 5 Hz tail shake oscillation in certain flight conditions. This mode was treated as a significant threat relevant to feedback of yaw rate and attitude to the directional axis.

Others - Additional signal flow paths associated with VSC system crossfeeds (or coupling) were identified as lower level threats to stability. These crossfeed paths are enabled by aircraft design features such as the rotor hinge offset and the SH-60 canted tailrotor. There were no hard data available on these modes. However the knowledge of these coupling mechanisms focused attention during the analysis of the data from the crossfeed tests.

Tracking the Closed Loop Gain Margin

Various time and frequency domain stability tracking schemes were considered. The frequency domain method described below was proposed and approved by the NAVAIR flight clearance office.

The method uses baseline open loop frequency response data to estimate the limit VSC gain that can be used without exceeding the closed loop gain or phase limits of 6 db and 45 degrees respectively. The frequency sweeps were limited to a maximum magnitude of one inch and frequency of two Hz.

The major steps of this method are listed below. Example data from the roll axis are shown in figures 2 and 3.

- Lateral control frequency sweeps of up to one inch is generated by the pilot from a low frequency of approximately 0.5 Hz to a maximum of 2 Hz. (figure 2)

- The frequency response for the loop is determined. Both specialized and off the shelf spectral estimation algorithms were used.

- The open loop frequency response results are plotted in the standard Nichols form of gain on the y axis and phase on the x axis. Figure 3 shows the results for the example lateral sweep.

- The allowable gain for the loop is then estimated by measuring the vertical distance (in db) that the data can be slid vertically to meet the required stability margin.

- This gain, measured in db, is converted to a maximum or minimum value to be entered in the CCS. The value range for input to the CCS is 000 to 999 with 500 corresponding to zero gain.

The VSC gain is then changed towards the predicted gain limit, a closed loop frequency sweep performed and then the actual closed-loop frequency response is compared to the frequency response predicted from the open loop data.

If the agreement is good then the tracking method is considered validated, and the process is repeated until the limit gain is reached.

If the agreement is not adequate, the reason for the disparity is resolved. If the reason can't be resolved, the most conservative interpretation of the data is made and the process continued.

Off-Axis Effects

The above gain limit is considered valid for the aircraft configuration of the tests. This configuration includes the conventional parameters such as loading and weight, and also the other off-axis configuration parameters such as VSC gain and lead/lag values. The off-axis VSC gains along with helicopter cross coupling response may cause the predicted gain limit to change when off-axis gains are changed.

Since the off-axis effects are prevalent in the helicopter, the method of tracking the stability margin is subject to the above effects. These effects were in part responsible for the scatter band observed in the data. The VSC gain limits were estimated from the conservative (upper) side of the scatter band of the Nichols data thus reducing the magnitude of the predicted limit gain value. More refined approaches are available to address these off-axis effects [7]. These approaches will reduce the error band applied to the data and will "carve out" additional portions of the VSC gain envelope thus expanding the capability of the system.

Test Procedures

For all flights, variations of a specific gain were terminated if any one of the following conditions occur:

- Predicted closed loop gain margin of less than 6 db or 45 degrees
- The onset of any structural/rotor mode or excessive vibration as determined by onboard data analysis, air crew, or ground observer
- Unacceptable handling qualities (as indicated by a tendency towards an instability, excessive workloads or pilot induced oscillations)
- Sufficient gain level for instructional use
- Maximum or minimum gain setting (available on the CCS) was reached

A incremental progression to the maximum and minimum values was used to determine the limiting gain values (or combinations of gain settings) that could be used without encountering the above termination conditions.

Special Precautions

Special precautions used included:

- Hazard Analysis [5]
- Electro Magnetic Compatibility Safety Of Flight Tests (EMC SOFT)
- Strict adherence to termination conditions

- A NAVAIRWARCENACDIV Safety Checklist was completed.
- Gains were adjusted in an incremental fashion
- AUTOPILOT was OFF for all VSC operation (Except early AFCS fault monitoring tests)
- Real-Time VSC actuator monitoring

Test Results

The VSC gain ranges were determined during the Phase I and Phase II development tests and are presented in Table 1 and Figure 4. The gain levels in Figure 4, set at 500 (zero VSC gain), are presently assigned to less important VSC parameters, and were not developed. These excess channels, the result of using the Learjet VSC as the basis of for the SH-60B design, are channels available for future system growth.

The gain limits shown in figure 4 were based on several of the termination conditions listed previously. A summary of the gain limiting conditions is presented in Table 2. Gain limits in most cases determined by the minimum or maximum CCS settings. Other factors limiting the maximum gain were gain/phase margin, and for the directional axis with heading feedback, excessive saturation of the VSC actuator.

The overall VSC system's gain envelope is adequate for USNTPS flight demonstrations. The system represents a significant improvement over the capability of the NCH-46 VSC and the design architecture has excellent potential for growth.

VSC System Reliability

There was early concern that the VSC system designed for a fixed wing airplane would have poor reliability when installed in a helicopter. There were, however, no significant VSC system failures in over 100 flight hours of system operating time plus an additional 100 hr. of flight time with the system in a non-powered state. Two minor system failures occurred which required local maintenance action. They were a light bulb change and straightening of a bent VSC connector pin. Although the limited amount of data does not allow a statistically significant estimate of reliability, the trouble free operation to date suggests a highly reliable system.

CCS Operation

The management of the VSC system was evaluated by the instructor/safety pilots during ground and flight operation. The operation of the VSC system was via the CCS and associated control panels and cockpit switches. The instructor is able to quickly change VSC configurations by indexing through prestored VSC configuration gain sets. The time required to change configurations is approximately 5-10 seconds (the SOW allowed up to 30 sec.). The operation of the system required minimum attention away from the instructor's primary duties and will allow the maximum amount of training during each flight. The CCS operation represents a significant improvement over the NCH-46 VSC and is a enhancing feature of the NSH-60B VSC.

Trip System Performance

The VSC system can be disengaged (or tripped) from the SAS actuators by the safety trip system. This trip system has two modes: 1) the manual mode which allow either the instructor or evaluation pilot to trip the system, and 2) the auto safety trip mode which generates a trip independent of pilot action.

Manual Mode

The manual safety trip was checked prior to each flight and was used as the primary method to disengage the system. The manual safety trip never failed to work correctly and was never used to trip the system as the result of an adverse event such as an oscillatory divergence or VSC induced vibration.

Auto Mode

The auto safety trip system is activated by a difference between the commanded and actual SAS actuator position. If the difference is more than 4 volts for 100 ms, the safety trip system actuates and returns the control of the SAS actuator to the host aircraft. The above volts-time threshold values were used during all engineering development tests to date and represented a tradeoff between

catching significant VSC failures, and producing unwanted trips or false alarms. During the development testing, the trip system thresholds were set at low values (a "hair trigger") which produced a high rate of false alarm safety trips. This high occurrence of false alarms was considered acceptable during development testing since an added degree of protection was afforded against unknown or miss-predicted instabilities. At the completion of the development phase the safety trip system thresholds were increased to allow representative mission tasks to be flown for the syllabus development flights.

There were no observed cases where the auto safety trip system made a significant save from an adverse occurence such as an oscillatory divergent actuator motion.

Description of VSC Flight Exercises

One interim and two syllabus VSC system exercises have been developed and are described below.

Interim VSC Exercise

A prototype VSC exercise was developed and presented to USNTPS staff and class. The gain envelope use was limited to that cleared to August 1993. The scope of the demonstration was a cross section of the VSC I and VSC II exercises described below.

VSC I

This exercise is the first helicopter VSC in the syllabus and is conducted in week 22 of the 48 week course. Academic instruction discussing the effects of sensitivity and damping on the response characteristics of the helicopter is followed by a simulator laboratory reviewing the effects discussed in the classroom and summarizing the basic test techniques used for inflight estimation of sensitivity and damping. A fixed task is flown while the VSC system is used to demonstrate a systematic variation of lateral control sensitivity and roll damping. A handling qualities evaluation is conducted where Cooper-Harper ratings are assigned and then analyzed in a post flight review.

VSC II

This exercise is conducted in week 29. Academic instruction discussing the sources of coupling is followed by a simulator laboratory reviewing the effects discussed in the classroom and specialized test techniques used for inflight estimation of control and rate coupling. A variety of fixed tasks are flown while the VSC system is used to demonstrate variations of control and rate coupling. Various response types and control delays are also demonstrated.

Future NSH-60B VSC Developments

VSC system enhancements, identified as being desirable to improve the effectiveness of the system, are:

- Increase the VSC system authority - will allow more aggressive mission tasks to be performed without saturation of the system
- Optimize the safety trip system - will allow a better balance between the protection afforded and the false alarm rate of the trip system
- Add other feedback variables - will allow demonstration of additional response type such as Translational Rate Command
- Add a variable feel system - will allow in-flight demonstration of the significant influence of the feel system on flying qualities
- Improve quality of existing VSC sensor signals - improvement of the quality of the input signals by sensor relocation and refinement of the signal conditioning will reduce the signal noise levels
- Improve the methods for testing and data analysis - will reduce the time and increase the accuracy of future VSC testing

Summary

Simulation has been used as a teaching tool at the USNTPS since the introduction of the VSC aircraft program in 1960. In-flight simulators have proven valuable for the teaching aircraft dynamics, controls and display system characteristics, and their combined effect on handling qualities.

Basic methods of implementing the

VSC were reviewed and past and current systems used at the USNTPS were discused. A general description of a response feedback VSC system was presented and the various subsystems were described. Criteria for selection of the host airframe, and the specific performance requirements of a VSC installed in a NSH-60B helicopter were presented. The VSC program elements of design, implementation, and testing were reviewed and potential improvements were summarized.

The overall effectiveness of the VSC system was validated by compliance with initial VSC system requirements, compliance with other gineering performance measures, qualitative evaluations of the test pilot/ instructors and the reactions and critiques of evaluation pilots.

The following VSC system features were considered enhancing:

- A trip system that always worked
- Trouble free (reliable) operation
- Low workload to manage the VSC
- Lack of engage transients
- Acceptable disengage transients
- Pilot comfort down to 20 feet AGL
- Adequate authority in the roll and pitch axis

The VSC provided a training facility that replaces and advances the capability of the NCH-46 VSC and provides growth potential for future enhancements.

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FTEG (Rotary Wing): Lew Fromhart
Calspan : Ralph Siracuse

Also instrumental were members of the USNTPS/DYNCORP maintenance team.

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Table 1
VSC Gain Summary

GAIN NO.	Parameter	CCS MIN	CCS MAX	GAIN NO.	Parameter	CCS MIN	CCS MAX
1	Pitch Damping	0	990	33	Ped to Lat	0	999
2	Roll Damping	0	784	34	Col to Lat	0	999
3	Yaw Damping	0	999	35	q to Ped	200	780
4	Pitch Sensitivity	0	999	36	p to Ped	200	800
5	Roll Sensitivity	0	999	37	Long to Ped	0	999
6	Pedal Sensitivity	0	999	38	Lat to Ped	0	999
7	Pitch Attitude Feedback	450	677	39	Col to Ped	0	999
8	Roll Attitude Feedback	350	750	40	p to Long - Lead	500	500
9	Heading Feedback	450	700	41	p to Long - Lag	500	500
10	Long Lead	500	800	42	r to Long - Lead	500	500
11	Long Lag	500	800	43	r to Long - Lag	500	500
12	Lat Lead	500	800	44	Lat to Long - Lead	500	500
13	Lat Lag	500	800	45	Lat to Long - Lag	500	500
14	Ped Lead	500	800	46	Ped to Long - Lead	500	500
15	Ped Lag	500	800	47	Ped to Long - Lag	500	500
16	q Lead	500	500	48	q to Lat- Lead	500	500
17	q Lag	500	500	49	q to Lat - Lag	500	500
18	p Lead	500	500	50	r to Lat - Lead	500	500
19	p Lag	500	500	51	r to Lat - Lag	500	500
20	r Lead	500	500	52	Long to Lat - Lead	500	500
21	r Lag	500	500	53	Long to Lat - Lag	500	500
22	Long T Delay	20	999	54	Ped to Lat - Lead	500	500
23	Lat T Delay	20	999	55	Ped to Lat - Lag	500	500
24	Ped T Delay	20	999	56	p to Ped - Lead	500	500
25	p to Long	0	999	57	p to Ped - Lag	500	500
26	r to Long	250	800	58	Long to Ped - Lead	500	500
27	Lat to Long	0	999	59	Long to Ped - Lag	500	500
28	Ped to Long	0	999	60	Lat to Ped - Lead	500	500
29	Col to Long	0	999	61	Lat to Ped - Lag	500	500
30	q to Lat	250	650	62	Col to Ped - Lead	500	500
31	r to Lat	200	650	63	Col to Ped - Lag	500	500
32	Long to Lat	0	999	64	q to Ped - Lag	500	500

Table 2
Factors Limiting Maximum VSC Gains

REASON FOR TERMINATION	PERCENT OF GAINS IN THIS CATEGORY
Reached Closed Loop Gain Margin	15
Structural/Rotor Mode, Vibration	0
Unacceptable Handling Qualities	0
Sufficient Gain for Instruction	24
Maximum or Minimum CCS Gain Setting	55

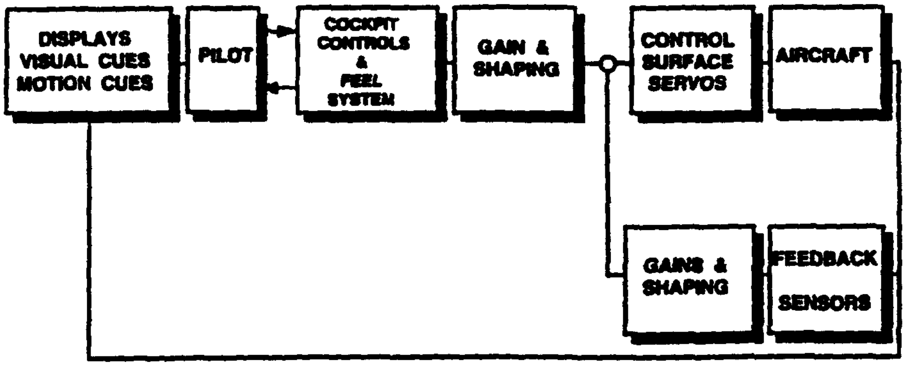

Fig. 1. Pilot-Vehicle System

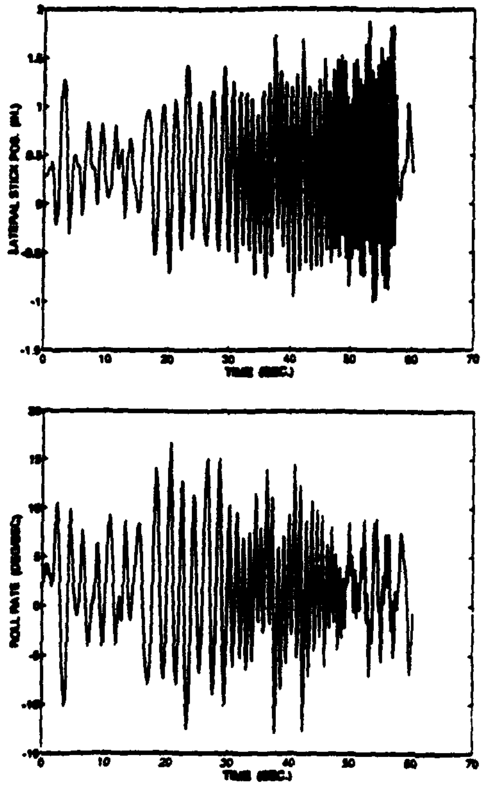

Fig. 2. Frequency Sweep

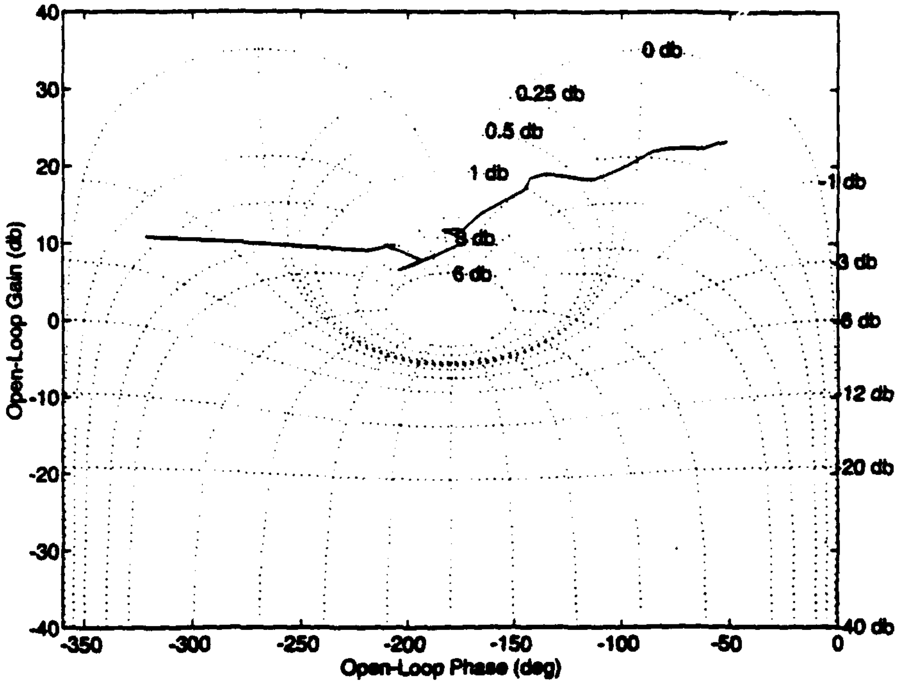

Fig. 3. Nichols Plot - Lateral Sweep

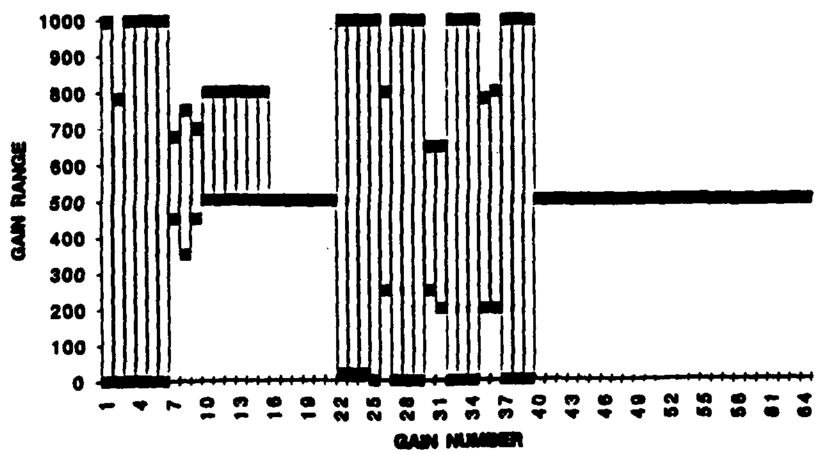

Fig. 4. Graphical Summary of VSC Gain Ranges